SVHEAT™

2D / 3D Geothermal Modeling Software

Tutorial Manual

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1 Introduction 4
2 Heated Pipeline 5
2.1 Model Setup 6
2.2 Results & Discussion 14
3 Heated Foundation 17
3.1 Model Setup 18
3.2 Results & Discussion 29
4 References 31

1 Introduction

The Tutorial Manual serves a special role in guiding the first time users of the SVHEAT software through a typical example problem. The example is "typical" in the sense that it is not too rigorous on one hand and not too simple on the other hand.

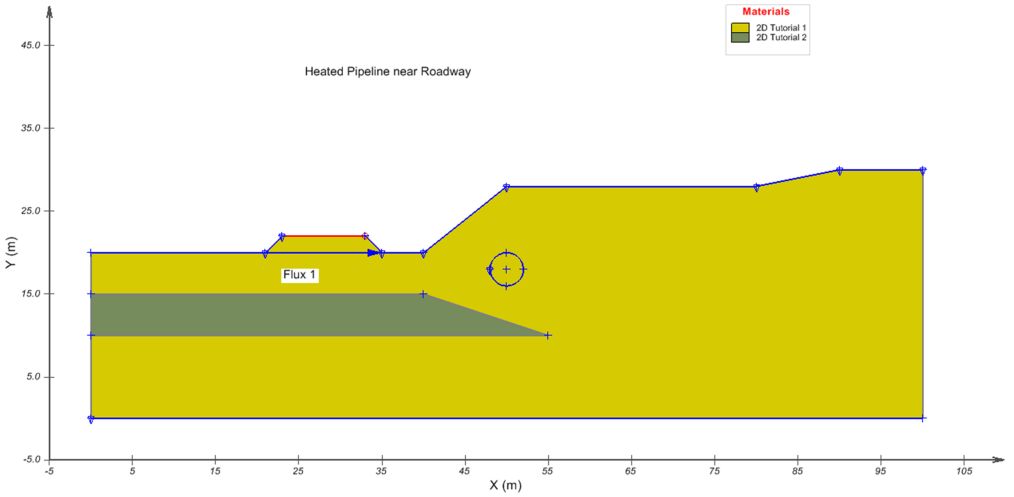
The Tutorial Manual serves as a guide by: assisting the user with the input of data necessary to solve the boundary value problem, ii.) explaining the relevance of the solution from an engineering standpoint, and iii.) assisting with the visualization of the computer output. An attempt has been made to ascertain and respond to questions most likely to be asked by first time users of SVHEAT.

2 Heated Pipeline

The following example introduces some of the basic features of SVHEAT and sets up a model of a buried pipeline. The purpose of this model is to determine the effects of the heated pipeline on the frozen ground and the nearby roadway. This steady-state model is composed of two regions and two materials. The model data and material properties are provided below.

Project: Highway
Model: PipeLineTut2D
Minimum authorization required: STUDENT

Model Description and Geometry



Slope Region **Seam Region**

Shape 1 - polygon **Shape 2 -Circle**

X	Y			X	Y		X	Y
0	0		Center:	50	18		0	10
100	0						55	10
100	30		Radius:	2			40	15
90	30						0	15
80	28							
50	28							
40	20							
35	20							
33	22							
23	22							
21	20							
0	20							
0	15							
0	10							

Material Properties

The only soil properties required to solve this problem are those related to thermal conductivity since a steady-state analysis is being performed.

Material 1 - Slope Region: Thermal Conductivity curve laboratory data:

Temperature (ºC)	Conductivity (J/hr-m- ºC)
-10	1.58E+05
-1	1.57E+05
-0.1	1.56E+05
0	1.43E+05
0.1	1.28E+05
1	1.29E+05
10	1.30E+05

Material 2 - Seam Region: Thermal Conductivity curve laboratory data:

Temperature (ºC)	Conductivity (J/hr-m- ºC)
-10	2.00E+05
-1	1.90E+05
-0.1	1.80E+05
0	1.50E+05
0.1	1.30E+05
1	1.25E+05
10	1.20E+05

2.1 Model Setup

The following steps are required in order to set up and solve the model described in the preceding section. The steps fall under the general categories of:

a. Create model
b. Enter geometry
c. Specify boundary conditions
d. Apply material properties
e. Specify model output
f. Run model
g. Visualize results

a. Create Model

The following steps are required to create the model:

1. Open the *SVOFFICE Manager* dialog,

2. Create a new project called "UserTutorial" by pressing the *New* button next to the list of projects,
3. Create a new model called "Heated_Pipeline" by pressing the *New* button next to the list of models. The new model will be automatically added under the recently created UserTutorial project. Use the settings shown below when creating a new model,
4. Select the following:

Application:	SVHEAT
System:	2D
Type:	Steady-State
Units:	Metric
Time Units:	Seconds (s)

5. Click on *OK*.

Before entering any model geometry it is best to set the World Coordinate System to ensure that the model will fit into the drawing space.

1. Access the *World Coordinate System* tab by selecting the *World Coordinate System* tab on the *Create New Model* dialog,
2. Enter the World Coordinates System coordinates shown below into the dialog,

x - minimum:	-5
y - minimum:	-5
x - maximum:	105
y - maximum:	40

3. Click *OK* to close the dialog.

The workspace grid spacing needs to be set to aid in defining region shapes. The Seam Region in this example consists of a filter type material. The filter material of the model has coordinates of a precision of 0.5m. In order to draw any aspect of the geometry with this precision using the mouse, the grid spacing must be set to a maximum value of 0.5.

1. Select *View* > *Options* from the menu to access the Grid Spacing,
2. Enter 0.5 for both the horizontal and vertical spacing, and
3. Click *OK* to close the dialog.

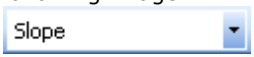
b. Enter Geometry

A region is the basic building block for a model. A region represents both a physical portion of material being modeled and a visualization area in the SVHEAT CAD workspace. A region will have a set of geometric shapes (e.g., polygons, circles, etc.) that define its material boundaries. Other modeling objects include features, such as flux sections, text, and line art. These features can be defined on any given region.

The present model is divided into two regions; namely the Slope region and the Seam region. Use the following steps to add the necessary regions:

1. Open the *Regions* dialog by selecting *Model* > *Geometry* > *Regions* from the menu,
2. Change the first region name from Region 1 (i.e., R1) to Slope. To do this, highlight the name and type the new name Slope,
3. Press the *New* button to add a second region,
4. Change the name of the second region to Seam, and
5. Click *OK* to close the dialog.

The shapes that define each material region are now created. Note that when drawing a geometric shape, information will be added to the region that is current in the Region Selector. The Region Selector is found at the top of the workspace and appears in the following image:



- **Define the Slope Region – Shape 1**
  Shape 1 refers to the entire region consisting of material 1.

1. Select "Slope" as the region by going to *Model* > *Geometry* > *Regions* and clicking on "Slope",
2. Select *Draw* > *Model Geometry* > *Region Polygon* from the menu,
3. The cursor will now be changed to cross hairs,
4. Move the cursor near (0,0) in the drawing space. You can view the coordinates of the current position of the mouse in the status bar just below the drawing space,
5. To select the point as part of the shape, left click on the point,
6. Now move the cursor near (100,0). Left click on the point. A line is now drawn from (0,0) to (100,0),
7. Repeat this process for the remaining points as provided at the beginning of this tutorial. This will define the geometry of the Slope Region,
8. For the last point (0,10), double-click on the point to finish the shape. A line is now drawn from (0,15) to (0,10) and the shape is automatically finished. SVHEAT will draw a line from (0,10) back to the starting point, (0,0).

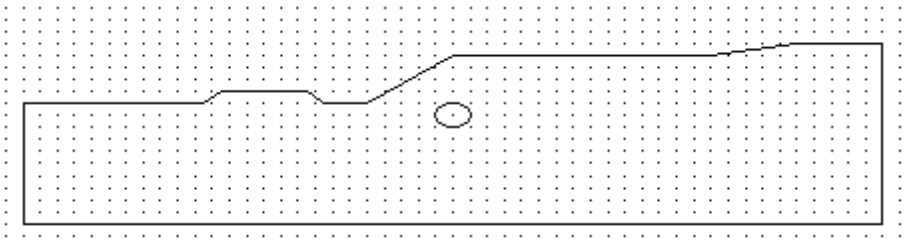
N O T E :
At times it may be somewhat tricky to snap onto a grid point that is near a line defined for a region. Turn the object snap off by clicking on *OSNAP* in the status bar to alleviate this problem. It should also be noted that shapes should, in this case, be drawn counter clockwise.

- **Define the Slope Region – Shape 2**
  Shape 2 refers to the geometry of the heated pipeline.

9. Ensure the Slope region is current in the region selector,

10. Select *Draw* > *Model Geometry* > *Region Circle* from the menu,
11. The cursor will now be changed to cross hairs,
12. Move the cursor near (50,18) in the drawing space. You can view the coordinates of the current position of the mouse in the status bar just below the drawing space,
13. To select the point as the circle center left click on the desired point,
14. Drag the cursor out to a *radius* of 2,
15. Let go of the mouse button to finish the circle,
16. To ensure that the radius is set to 2, open the double-click on the circle shape to open the *Region Properties* dialog,
17. Enter a radius of 2 if necessary,
18. Click *OK* to close the *Region Properties* dialog,

If the slope geometry been entered correctly the shape should look as follows:



NOTE:
If a mistake was made entering the coordinate points for a shape. Select a shape with the mouse and select *Edit* > *Delete* from the menu. This will remove the entire shape from the region. To edit the shape use the *Region Properties* dialog.

- **Define the Seam Region**

The Seam Region corresponds to material 2 in the layout of the example,

19. Ensure that Seam is current in the region selector,
20. Select *Draw* > *Model Geometry* > *Region Polygon* from the menu,
21. The cursor will now be changed to cross hairs,
22. Move the cursor near (0,10) in the drawing space. You can view the coordinates of the current position of the mouse in the status bar just below the drawing space,
23. To select the point as part of the shape left click on the point,
24. Now move the cursor near (55,10). Left click on the point. A line is now drawn from (0,10) to (55,10),
25. Now move the cursor near (40,15). Left click on the point. A line is now drawn from (55,10) to (40,15), and

26. For the *last point* (0,15), right click to snap the cursor to the point. Double-click on the point to finish the shape. A line is now drawn from (40,15) to 0,15) and the shape of the seam is automatically finished. SVHEAT will draw a line from (0,15) back to the start point, (0,10).

The diagram will appear as shown at the beginning of this tutorial after all the region geometries have been entered.

c. Specify Boundary Conditions

Boundary conditions must be applied to the points associated with each region. Once a boundary condition is applied to a boundary point, this defines the starting point for that particular boundary condition. The boundary condition will then extend over subsequent line segments around the edge of the region in the direction in which the region shape was originally entered. Boundary conditions remain in effect around a shape until they are re-defined. The user may not define two different boundary conditions to the same line segment.

More information on boundary conditions can be found in *Menu System* > *Model Menu* > *Boundary Conditions* > *2D Boundary Conditions* in your User's Manual.

Now that all of the regions of the model geometry have been successfully defined, the next step is to specify the boundary conditions. An approximate geothermal gradient of 1°C/30m will be simulated by setting the temperature at the ground surface to -6 °C and the surface at the base of the model to -5 °C. The temperature of the pipe is 9 °C and the heat generated by the warming of the roadway is set as 200 kJ/hr (i.e., a thermal flux boundary condition). The steps associated with specifying the boundary conditions are as follows:

- **Slope Region – Shape 1**

1. Select the Slope dominant region in the drawing space,
2. From the menu select *Model* > *Boundaries* > *Boundary Conditions*. The boundary conditions dialog will open,
3. Select point (0,0) from the list,
4. From the *Boundary Condition* drop-down menu, select a "Temperature Expression" boundary condition. This will cause the Temperature Expression box to be enabled,
5. In the Constant/Expression box enter a temperature of -5,
6. Select the point (100,0) from the list,
7. From the Boundary Condition drop-down select a "Zero Flux" boundary condition,
8. Repeat for the remaining points referring to this table:

X	Y	Boundary Condition	Expression
0	0	Temperature Expression	-5
100	0	Zero Flux	
100	30	Temperature Expression	-6
90	30	Zero Flux	

80	28	Continue	
50	28	Continue	
40	20	Continue	
35	20	Continue	
33	22	Flux Expression	200000 (J/hr/m^2)
23	22	Temperature Expression	-6
21	20	Continue	
0	20	Zero Flux	
0	15	Continue	

NOTE:
The Temperature Expression boundary condition for the point (100,30) becomes the boundary condition for the following line segments that have a Continue boundary condition until a new boundary condition is specified. By specifying a Flux Expression condition at point (33,22) the Continue boundary condition is stopped.

- **Slope Region – Shape 2**

9. Select the Slope circle region from the drawing space,
10. From the menu select *Model* > *Boundaries* > *Boundary Conditions* to open the *Boundaries* dialog,
11. In the Boundary Condition drop down select a Temperature Expression boundary condition,
12. Enter the value 9, and
13. Click *OK* to save the input Boundary Conditions and return to the workspace.

d. Apply Material Properties

The next step in defining the model is to enter the material properties for the two materials that are used for the model. A material called *2D Tutorial 1* is defined for the major material region (i.e., Slope Region) and the material called *2D Tutorial 2* is defined for the smaller material region (i.e., Seam Region). This section will provide instructions on creating the first material. Repeat the process to add the other material.

1. Open the *Materials* dialog by selecting *Model* > *Materials* > *Manager* from the menu,
2. Click the *New...* button to create a material,
3. Enter 2D Tutorial 1 for the material name,
4. The Material Properties dialog should pop-up automatically,

NOTE:
When a new material is created, the display color of the material can be specified using the Fill Color box in the Material Properties menu. Any region that has a material assigned to it will display the corresponding material fill color.

5. Move to the *Conductivity* tab. Select *Data* from the Unsaturated Thermal

Conductivity drop-down and press the *Data* button,

6. Enter the laboratory data points as provided in the "A Two Dimensional Example Model" section at the beginning of this Tutorial,
7. Click the Volumetric Heat Capacity tab,
8. Select the Constant radio button,
9. Enter 1.95e6 for the Frozen VHC and Unfrozen VHC text field,
10. Click *OK* on all open dialogs to accept the changes made and return to the *Materials Manager* menu, and
11. *Repeat* these steps to create the second material.

NOTE:
To view the thermal conductivity curve of the laboratory data press the *Graph* button on the bottom right of the *Thermal Conductivity Data* dialog.

The materials will also need to be applied to the model regions. Follow these instructions in order to assign the materials to regions:

1. Open the *Regions* dialog by selecting *Model* > *Geometry* > *Regions* from the menu,
2. For the Slope region, select *2D Tutorial 1* from the Material drop-down, and
3. For the Seam region, select *2D Tutorial 2* from the Material drop-down.

e. Specify Model Output

Flux sections can be used to show the rate of heat flow across a portion of the model for a steady state analysis and the rate of heat flow moving across a portion of the model in a transient analysis.

1. Select *Draw* > *Flux Section* from the menu to open the Flux Section,
2. Click on the point (21,20) with the mouse,
3. To finish the Flux Section, double-click on *point* (35,20). A blue line with an arrow on the end should be drawn across the geometry,
4. Default plots will be generated for reporting the results from the flux section will automatically be generated, and
5. Notice that the flux section label is partially on the region boundary in the workspace. To move the label location, select the textbox in the workspace and drag it to the desired location.

NOTE:
Flux Section labels can be formatted in the same manner as regular text boxes.

Two levels of output may be specified: i) output (graphs, contour plots, fluxes, etc.) which are displayed during model solution, and ii) output which is written to a standard finite element file for viewing with ACUMESH software. Output is specified in the following two

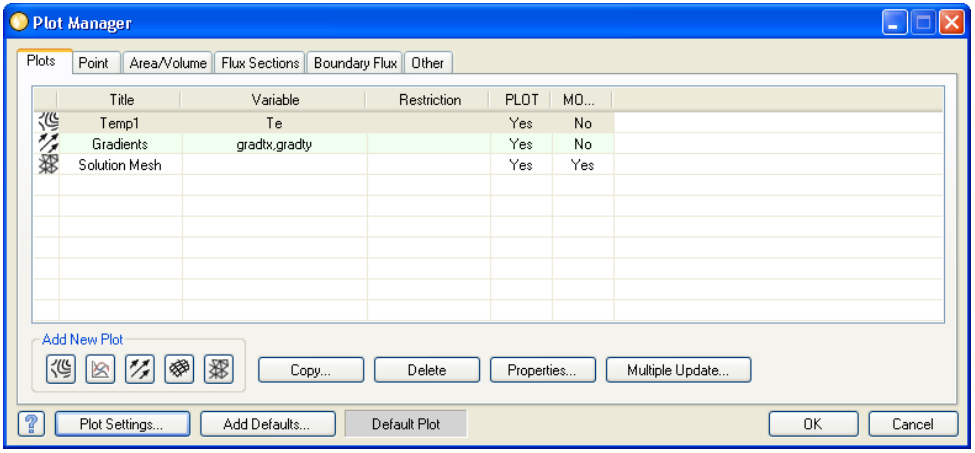
dialogs in the software:

i) Plot Manager: Output displayed during model solution.
ii) Output Manager: Standard finite element files written out for visualization in ACUMESH or for inputting to other finite element packages.

PLOTMANAGER

The *Plot Manager* dialog is first opened to display appropriate solver graphs. There are numerous plot types that can be specified to visualize the results of the model. Three plots will be generated for this tutorial example: temperature contours, thermal gradient vectors, and the final solution finite element mesh.

1. Open the *Plot Manager* dialog by selecting *Model* > *Reporting* > *Plot Manager* from the menu,
2. The toolbar at the bottom left corner of the dialog contains a button for each plot type. Click on the *Contour* button to begin adding the first contour plot. The *Plot Properties* dialog will open,
3. Enter the title Temp1,
4. Select *Te* as the variable to plot from the drop-down,
5. Turn off the Monitor output option under the *Output Options* tab,
6. Click *OK* to close the dialog and add the plot to the list,
7. Repeat these steps 2 to 6 to create the remaining plots shown below. Note that the Mesh plots do not require the entry of a variable, and



8. Click *OK* to close the *Plot Manager* and return to the workspace.

Boundary Flux plots should also be created for this model. In order to do this, complete the following steps:

1. Select *Model* > *Reporting* > *Plot Manager* from the menu,
2. Select the *Boundary Flux* tab,
3. Add a New Report for the bottom of the Slope region. By default this boundary was named BN1 when the boundary condition was defined for this segment,

4. Turn off the Monitor and Plot options for this Plot under the *Output options* tab,
5. Add a History Plot for the *X* flow, *Y* flow, and Normal flow variables, and
6. Repeat steps 3 to 6 for the Circle shape's boundary (BN7 by default).

OUTPUT MANAGER

Two output files will be generated for this tutorial example: a file of temperatures to be used as initial conditions in a subsequent transient analysis, and a .dat file to view the results in ACUMESH.

1. Open the *Output Manager* dialog by selecting *Model* > *Reporting* > *Output Manager* from the menu,
2. The toolbar at the bottom left corner of the dialog contains a button for each output file type. Click on the *ACUMESH* button to begin adding the output file. The *Output File Properties* dialog will open,
3. Enter the File Name ACUMESHOUT.
4. Click *OK* to close the dialog and add the output file to the list,
5. Create the temperature file by pressed the *SVHEAT File* button,
6. Click *OK* to close the dialog and add the output file to the list, and
7. Click OK to close the Output Manager and return to the workspace.

f. Run Model

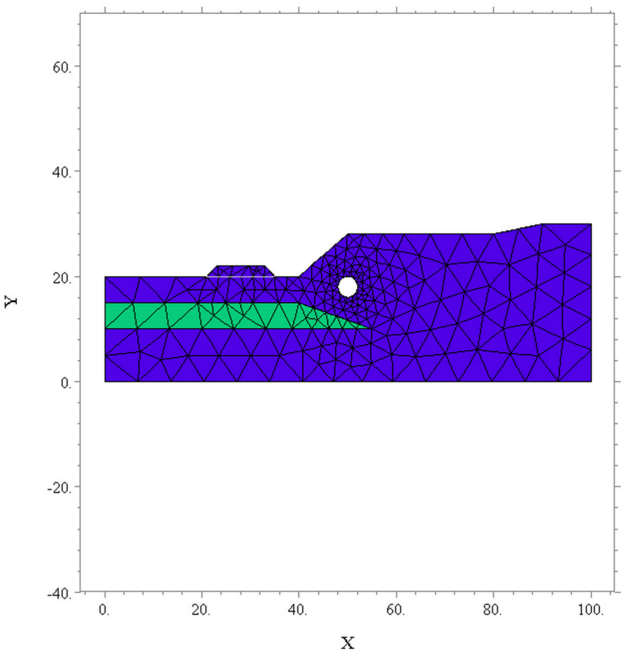
The next step is to analyze the model. Select *Solve* > *Analyze* from the menu. This action will write the descriptor file and open the FlexPDE solver. The solver will automatically begin solving the model.

g. Visualize Results

The visual results for the current model may be examined by selecting the *View* > *ACUMESH* menu option.

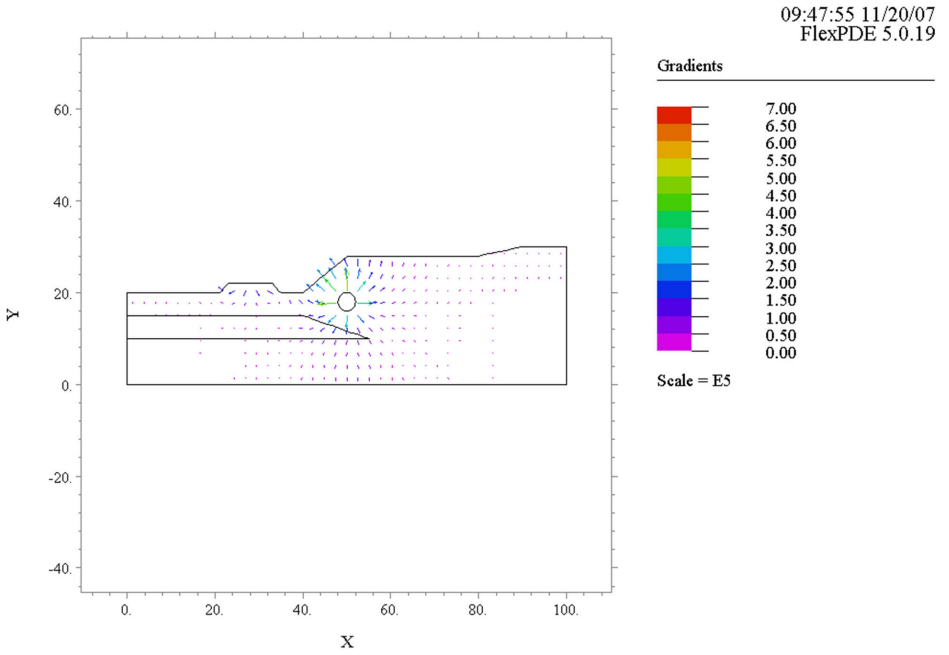
2.2 Results & Discussion

After the model has finished solving, the results will be displayed in the dialog of thumbnail plots within the SVHEAT solver. Right-click the mouse and select "Maximize" to enlarge any of the thumbnail plots. This section will give a brief analysis for each plot that was generated.



The Mesh plot displays the finite-element mesh generated by the solver. The mesh is automatically refined in critical areas such as around the pipe contact where there is a significant change in temperature.

The temperature contours indicate that the temperature of the pipe does not significantly influence the base of roadway. Instead the heat flux due to the warming of the roadway surface has an influence of a few degrees.



Gradient Vectors show both the direction and the magnitude of the heat flow at specific points in the model. Vectors show the heat flow is away from the pipeline, as anticipated.

X Component of Flow in (J/hr)= 0.000000
Y Component of Flow in (J/hr)= -434461.1

Normal
1. On External Region Boundary: Positive Flow is into Region
2. On Internal Region Boundary - Region Given: Positive Flow is into Given Region
3. On Internal Region Boundary - Region Not Given: Positive Flow is into First Applicable Region
4. Internal: Left Hand Rule

Normal Flow in (J/hr)= 434461.1

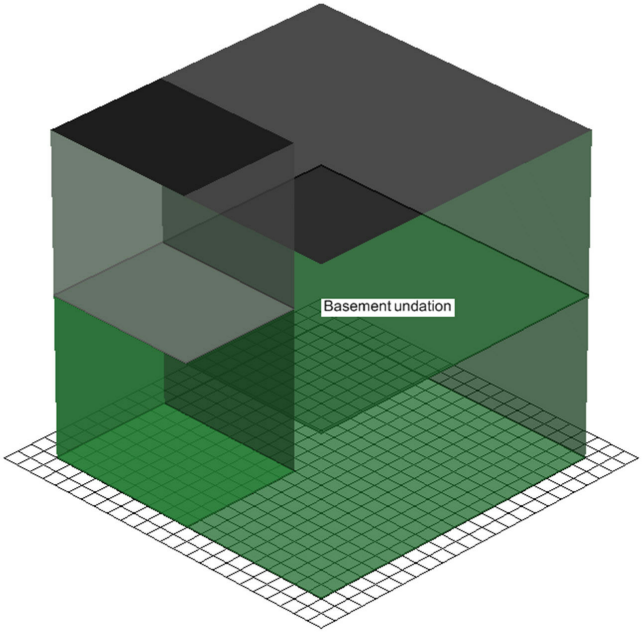
The Flux through the base of the roadway is displayed in the report dialog showing a breakdown of the *X, Y,* and normal components of flow through the model.

3 Heated Foundation

The following example will introduce you to a three-dimensional model in SVHEAT. The model is used to investigate steady-state heat flow through a material resulting from a heated foundation under winter conditions. The tutorial provides detailed set of instructions guiding the user through the creation of the 3D heat transfer model. The model is generated using two regions, three surfaces, and one material. The model data and material properties are provided below.

Project: Foundations
Model: HeatedFoundTut3D
Minimum authorization required: STUDENT

Model Description and Geometry



Region Shape Data for Tutorial – HeatedFoundation3D

Ground Region		Basement Region	
X	Y	X	Y
0	0	12	0
12	0	20	0
20	0	20	10
20	10	12	10
20	20		
12	20		
0	20		
0	10		

Material Properties

3D Tutorial Soil Material Properties

Temperature (°C)	Conductivity (J/s-m-°C)
-2	2000
-1	1999
0	1000
1	1001
2	1002

3.1 Model Setup

The following steps will be required in order to set up the model described in the preceding section. The steps fall under the general categories of:

a. Create model
b. Enter geometry
c. Specify boundary conditions
d. Apply material properties
e. Specify model output
f. Run model
g. Visualize results

a. Create Model

The following steps are required to create the model:

1. Open the *SVOFFICE Manager* dialog,
2. Select the project called "UserTutorial" by pressing the *New* button next to the list of projects. If the project does not exist, create a new project called "UserTutorial",
3. Create a new model called "HeatedFoundation3D" by pressing the *New* button next to the list of models. The new model will be automatically added under the recently created Tutorial project. Use the settings shown below when creating the new model:

   Application: SVHEAT
   System: 3D
   Type: Steady-State
   Units: Metric
   Time Units: Seconds (s)

The *Settings* dialog will contain information about the current model System, Type, Units, and Time Units. The thermal conductivity data for the materials contained in the model are reported as J/hr-m-°C. In this case, the data for the model is in metric units and the units information will remain unchanged.

Before entering any model geometry it is best to format the Axes to ensure that the model will fit into the drawing space.

1. Select the *World Coordinate System* tab. Enter the values shown below for the *X, Y* and *Z* dimensions,
2. Enter the World Coordinates System coordinates shown below into the dialog.

x - minimum:	-10
y - minimum:	-10
z - minimum:	0
x - maximum:	30
y - maximum:	30
z - maximum:	20

3. Click the *OK* button to close the *Create New Model* dialog and to create the new model.

The workspace grid spacing needs to be set to aid in defining region shapes. The geometry data for this model has coordinates of a precision of 1m. In order to effectively draw geometry with this precision using the mouse, the grid spacing must be set to a maximum value of 1.

1. The *View Options* dialog will appear,
2. Enter *1* for both the horizontal and vertical spacing, and
3. Click *OK* to close the dialog.

b. Enter Geometry

A region in SVHEAT is the basic building block for a model. A region represents both a physical portion of material being modeled and a visualization area in the SVHEAT CAD workspace. A region will have a set of geometric shapes that define its material boundaries. Also, other modeling objects including features, flux sections, text, and line art are defined on any given region.

This model will be divided into two regions, which are named Ground and Basement. Each region will have one of the materials defined specified as the region material. To add the necessary regions follow these steps:

1. Open the *Regions* dialog by selecting *Model* > *Geometry* > *Regions* from the menu,
2. Change the first *region name* from "R1" to *Ground*. Highlight the name and type new text,
3. Press the *New* button to add a second region,
4. Change the name of the second region to Basement, and
5. Click *OK* to close the dialog.

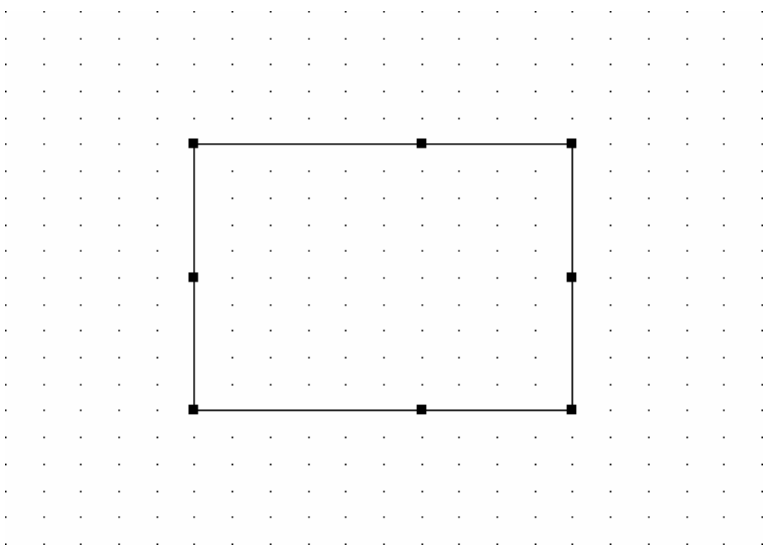
The shapes that define each region will now be created. Note that when drawing geometry

shapes the region that is current in the region selector is the region the geometry will be added to. The Region Selector is at the top of the workspace. Refer to the previous section of this manual for the geometry points for each region.

- **Define the Main region**

1. Specify "Ground" as the region by selecting *Model* > *Geometry* > *Regions* from the menu and clicking on "Ground",
2. Press *OK* to close the dialog,
3. Select *Draw* > *Model Geometry* > *Polygon Region* from the menu,
4. The cursor will now be changed to cross hairs,
5. Move the cursor near (0,0) in the drawing space. You can view the coordinates of the current position the mouse is at in the status bar just below the workspace,
6. To select the point as part of the shape left click on the *Point*,
7. Now move the cursor near (12,0) and then left click on the *Point*. A line is now drawn from (0,0) to (12,0),
8. Repeat this process for the remaining points. Refer to the previous section of this manual for the geometry points for each region,
9. For the last point (0,10). Double-click on the point to finish the shape. A line is now drawn from (0,20) to 0,10) and the shape is automatically finished by SVHEAT by drawing a line from (0,10) back to the start point, (0,0).

If the main geometry been entered correctly the shape should look like the following:



NOTE:
If a mistake was made entering the coordinate points for a shape then select a shape with the mouse and select *Edit* > *Delete* from the menu. This will remove the

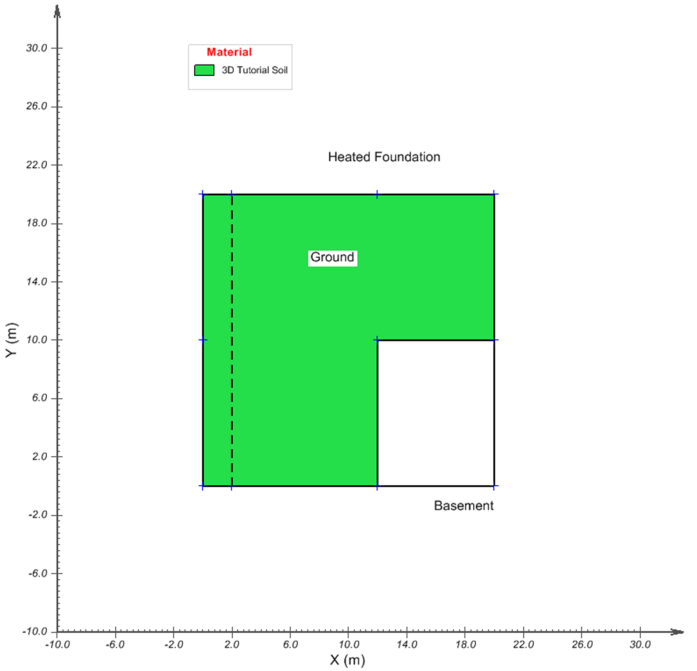
entire shape from the region. To edit the shape use the *Region Properties* dialog.

- **Define the Basement**

10. Select "Basement" as the region by going to *Model* > *Geometry* > *Regions*, and clicking on *Basement*,
11. Press *OK* to close the dialog,
12. Select *Draw* > *Model Geometry* > *Region Polygon* from the menu,
13. Move the cursor near (12,0) in the drawing space. You can view the coordinates of the current position of the mouse in the status bar just below the drawing space,
14. To select the point as part of the shape left click on the *Point,*
15. Now move the cursor near (20,0) and then left click on the *Point*. A line is now drawn from (12,0) to (20,0),
16. Now move the cursor near (20,10) and then left click on the *Point*. A line is now drawn from (20,0) to (20,10), and
17. For the last point (12,10). Double-click on the *point* to *finish the shape*. A line is now drawn from (20,10) to 12,10) and the shape is automatically finished by SVHEAT by drawing a line from (12,10) back to the start point, (12,0).

N O T E :
At times it may be somewhat tricky to snap to a grid point that is near a line defined for a region. Turn the object snap off by clicking on "OSNAP" in the status bar to alleviate this problem.

After all the region geometry has been entered it will have the appearance of the diagram below (without the coloring).



This model consists of three surfaces. Although it is not required, the two surface grids have the same dimensions and grid densities. By default every model initially has two surfaces.

- **Define Surface 1**

  This surface is already present so the next step is to define the grid lines.

  1. Select "Surface 1" as the region by going to *Model* > *Geometry* > *Surfaces*, and clicking on *Surface 1*,
  2. Press *OK* to close the dialog.
  3. Click *Model* > *Geometry* > *Surface Properties* in the menu to open the *Surface Properties* dialog,
  4. Select "Elevation Data" from the Definition Options drop-down,
  5. Select the *Elevations* tab and click the *Define Grid* button to set up the grid for the selected surface,
  6. There will be default grid lines of 0 and 10 present. Click the *Add Regular* button to open the *Add Regular X Gridlines* dialog,
  7. Enter -2 for Start, 1 for Increment Value, and 22 for End,
  8. Click *OK* to add the gridlines and *Close* the dialog,
  9. Click on *Define Grid* button again and move to the *Y* Grid Lines tab and repeat steps 7 to 8 for the *Y* gridlines,

Now that the grid has been set up, elevations must be specified for all the grid points:

10. Enter *0* in the Set Nulls field,
11. Click the *Set Nulls* button and all the missing elevations will be set to 0,
12. Click *OK* to store the elevations and close the dialog,

- **Define Surface 2**

  This surface is already present. Follow the steps for defining Surface 1 elevations except enter 10 in the Set Nulls field and press the *Set Nulls* button. This will set the Surface 2 elevations to 10m.

- **Define Surface 3**

  The following steps are required to add the third surface to the model. Since Surface 2 and Surface 3 have the same grid lines, Surface 2 grid will be copied during insertion of the new surface:

13. The *Surface* dialog can be opened by selecting *Model* > *Geometry* > *Surfaces* from the menu,
14. Click "New" to open the *Insert Surfaces* dialog,
15. Enter 1 as the Number of New Surfaces,
16. Select to place the new surface *At The Top,*
17. Select "Copy Grid" From An Existing Surface*,*
18. Select "Surface 2" from the drop-down,
19. Choose to *Include* the elevations,
20. Enter 10m as the offset from Surface 2. This will set the elevation of the *Z*-axis to 20m,
21. Press *OK* to add the surface, and
22. Click *OK* to close the dialog.

c. Specify Boundary Conditions

Boundary conditions must be applied to region points. Once a boundary condition is applied to a boundary point this defines the starting point for that particular boundary condition. The boundary condition will then extend over subsequent line segments around the edge of the region in the direction in which the region shape was originally entered. Boundary conditions remain in effect around a shape until re-defined. The user may not define two different boundary conditions over the same line segment.

More information on boundary conditions can be found in *Menu System* > *Model Menu* > *Boundary Conditions* > *2D Boundary Conditions* in your User's Manual.

Now that all of the regions and surfaces have been successfully defined, the next step is to specify the boundary conditions on the region shapes. A temperature of $-3^{o}C$ will be defined on the Ground region to simulate an outdoor temperature. The basement will be set to a temperature of $10^{o}C$.

Boundary conditions can only be defined using a 2D view. The steps for specifying the boundary conditions are as follows:

1. Change to the 2D view by selecting *View* > *Model* > *2D*,

2. Specify Ground as the region by selecting *Model* > *Geometry* > *Regions* from the menu and clicking on "Ground",
3. Press *OK* to close the dialog,
4. From the menu select *Model* > *Boundaries* > *Boundary Conditions*. The *Boundary Conditions* dialog will open and display the boundary conditions for Surface 1. These boundary conditions will extend from Surface 1 to Surface 2 over Layer 1,
5. Select "Surface 3" from the drop-down box located at the top right of the dialog,
6. Under the *Surface Boundary Conditions* tab, select a Temperature Expression boundary condition from the surface boundary condition drop-down box,
7. Enter –3 in the Constant/Expression field. Press *OK* to close the dialog,
8. Specify Basement as the region by selecting *Model* > *Geometry* > *Regions* from the menu and clicking on Basement,
9. Press *OK* to close the dialog,
10. From the menu select *Model* > *Boundaries* > *Boundary Conditions*. The *Boundary Conditions* dialog will open to the *Segment Boundary Conditions* tab and display the boundary conditions for Surface 1,
11. Select "Surface 2" from the drop-down box,
12. Select the point (12,0) from the list,
13. From the Boundary Condition drop-down select a "No BC" boundary condition,
14. Select the point (20,10) from the list,
15. From the Boundary Condition drop-down select a "Temperature Expression" boundary condition from the surface boundary condition drop-down box. This will cause the Constant/Expression box to be enabled,
16. In the Constant/Expression box enter a temperature of 10, and
17. Press *OK* to close the dialog.

d. Apply Material Properties

The next step in defining the model is to enter the material properties for the material in the model. A clay is defined for both the ground and the basement. This section provides instructions on creating the clay material.

1. Open the *Materials* dialog by selecting *Model* > *Materials* > *Manager* from the menu,
2. Click the *New...* button to create a material,
3. Enter "3D Tutorial Soil" for the material name,
4. Press *OK.* The dialog for the new material properties will pop up,

NOTE:
When a new material is created, you can specify the display a color for the material using the Fill Color box on the Material Properties menu. Any region that has a material assigned to it will display the material fill color.

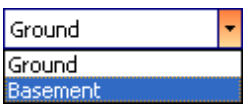
5. Move to the *Conductivity* tab,
6. Click on the *Data* button beside the Unsaturated Thermal Conductivity (ensure the Data appears on the drop-down menu before clicking the *Data* button),
7. Enter the *laboratory data points* as provided in the "A Three Dimensional Example Model" section at the beginning of this tutorial,

NOTE:
To view the laboratory data press the *Graph* button.

8. Click the *Volumetric Heat Capacity* tab,
9. Select the *Constant radio* button,
10. Enter 1.95e6 for the Frozen VHC and Unfrozen VHC text field, and
11. Click *OK* on all opened dialogs to accept the changes and close the dialogs.

Each region will cut through all the layers in a model creating a separate "block" on each layer. Each block can be assigned a material or be left as *void*. A void area is essentially air space. In this model all "blocks" will be assigned a material.

1. Specify "Ground" as the region by selecting *Model* > *Geometry* > *Regions* from the menu and clicking on "Ground",
2. Press *OK* to close the dialog,
3. Select *Model* > *Materials* > *Material Layers* from the menu to open the *Material Layers* dialog,
4. Select the "3D Tutorial Soil" material from the drop-down for Layer 2,
5. Select the "3D Tutorial Soil" material from the drop-down for Layer 1,
6. Click *OK* to close the dialog,
7. Select "Basement" in the Region Selector using the right arrow in the top right of the dialog,



8. Select *Model* > *Materials* > *Material Layers* from the menu to open the *Material Layers* dialog,
9. Select "VOID" from the drop-down blank for *Layer 2,*
10. Select the "3D Tutorial Soil" material from the drop-down for *Layer 1,* and

11. Close the dialog using the *OK* button.

e. Specify Model Output

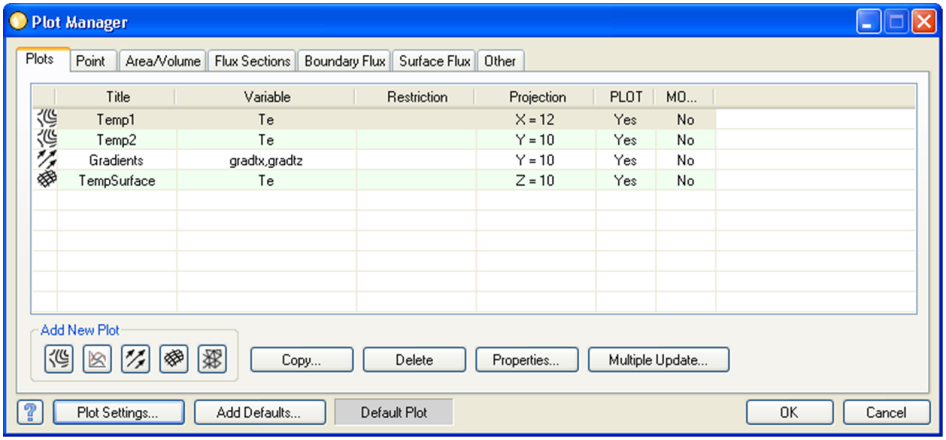
Two levels of output may be specified: i) output (graphs, contour plots, fluxes, etc.) which are displayed during model solution, and ii) output which is written to a standard finite element file for viewing with ACUMESH software. Output is specified in the following two dialogs in the software:

i) Plot Manager: Output displayed during model solution.
ii) Output Manager: Standard finite element files written out for visualization in ACUMESH or for inputting to other finite element packages.

PLOTMANAGER

The *Plot Manager* dialog is first opened to display appropriate solver graphs. There are many plot types that can be specified to visualize the results of the model. A few plots will be generated for this tutorial example model including a plot of the temperature contours on both an *X* and *Y* plane, gradient vectors, temperature surface plot, and the solution mesh.

1. Open the *Plot Manager* dialog by selecting *Model* > *Reporting* > *Plot Manager* from the menu,
2. The toolbar at the bottom left corner of the dialog contains a button for each plot type. Click on the *Contour* button to begin adding the first contour plot. The *Plot Properties* dialog will open,
3. Enter the title *Temp1,*
4. Select Te as the variable to plot from the drop-down,
5. Move to the *Projection* tab,
6. Select "Plane" as the Projection Option,
7. Select *X* from the Coordinate Direction drop-down,
8. Enter 12 in the Coordinate field. This will generate a 2D slice at X = 12m on which the temperature contours will be plotted,
9. Turn off the *Monitor* option under the *Output Options* tab,
10. Click *OK* to close the dialog and add the plot to the list,
11. Repeat steps 2 to 9 to create the remaining plots as shown below. Note that the Mesh plots do not require entry of a variable, and
12. Click *OK* to close the *Plot Manager* and return to the workspace.



OUTPUT FILES

Two output files will be generated for this tutorial example model: a transfer file of temperatures, and a .dat file to transfer the results to ACUMESH.

1. Open the *Output Manager* dialog by selecting *Model* > *Reporting* > *Output Manager* from the menu,
2. The toolbar at the bottom left corner of the dialog contains a button for each output file type. Click on the *ACUMESH* button to begin adding the output file. The *Output File Properties* dialog will open,
3. Enter the title AcuMeshOut,
4. Click *OK* to close the dialog and add the output file to the list,
5. Create the TempTransfer.trn transfer file by pressed the *Transfer File* button,
6. Select "Te" as the variable,
7. Click *OK* to close the dialog and add the output file to the list, and
8. Click *OK* to close the *Output Manager* and return to the workspace.

f. Run Model

The next step is to analyze the model. Select *Solve* > *Analyze* from the menu. This action will write the descriptor file and open the SVHEAT solver. The solver will automatically begin solving the model.

g. Visualize Results

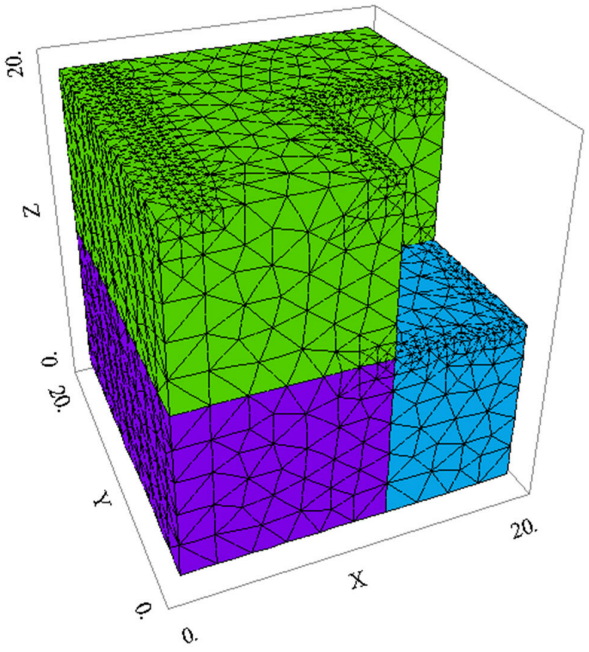
Once you have analyzed the model, the output plots can be visualized using ACUMESH. In order to view plots in ACUMESH, select *Window* > *ACUMESH* from the menu.

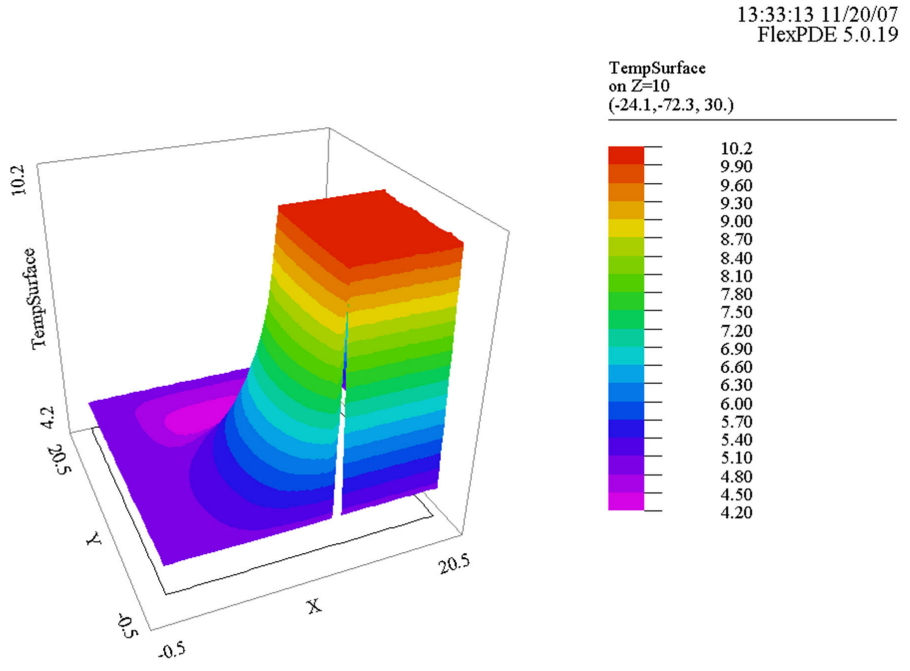
ACUMESH will prompt you to select the "Output file" to view. Choose *ACUMESHOut.dat* and click *OK* to open this file. Plots can visualized by selecting the desired process under Plots in the menu.

3.2 Results & Discussion

After the model has finished solving, the results will be displayed in the dialog of thumbnail plots within the SVHEAT solver.

Right-click the mouse and select "Maximize" to enlarge any of the thumbnail plots. This section will give a brief analysis for each plot that was generated.





Tutorial_HeatedFoundTut3D: Grid#4 p2 Nodes=25121 Cells=16396 RMS Err= 0.0059
Stage 1 Integral= 2541.165

4 References

FlexPDE 5.x Reference Manual, 2007. PDE Solutions Inc. Spokane Valley, WA 99206.